# NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

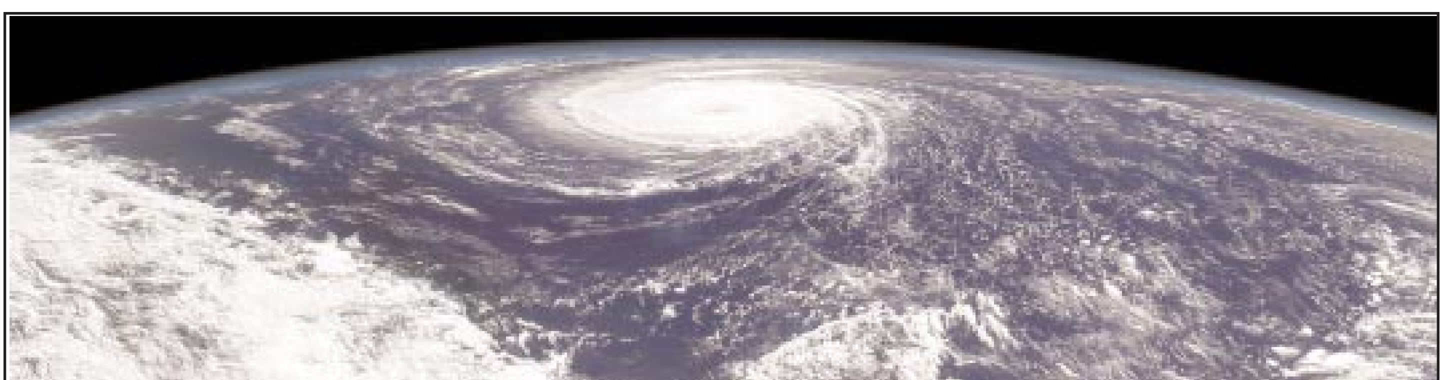
The National Aeronautics and Space Administration (NASA) Headquarters Weather Support Office has continued to improve NASA's weather support capabilities for both manned and unmanned space launch vehicles. It is expected that these improvements will strengthen and enhance the information provided to the ground-based decision-makers and astronaut observers to insure that NASA achieves the best operational posture for Space Shuttle launches and landings. The goal of the operations program is to provide the specialized meteorological data needed by operational forecasters at Cape Canaveral Air Station of Kennedy Space Center (KSC) and Johnson Space Center to support the Space Shuttle program. The focus is on detecting and forecasting the mesoscale weather events which strongly impact Shuttle ground processing, launches, and landing operations. NASA's also performs aviation research to improve safety, develop weather information technologies, and increase aviation system capacity. Advanced operations technologies can increase the number of operations per runway in all weather conditions. The research applies to both commercial and general aviation.

**OPERATIONS**

The goal of the National Aeronautics and Space Administration (NASA) operations program is to provide the specialized meteorological data and techniques needed by forecasters at Cape Canaveral Air Station and the Spaceflight Meteorology Group (SMG) at Johnson Space Center (JSC) to support the Space Shuttle and Expendable Launch Vehicle (ELV) programs. The focus is on observing and forecasting the mesoscale weather events that strongly impact ground processing, launch, and landing operations.

This goal requires exploitation of the latest technology. The Applied Meteorology Unit (AMU), co-located with the Air Force's Range Weather Operations, provides a facility to develop, evaluate and, if warranted, transition new meteorological technology into operations. For instance, the AMU strives to develop techniques and systems to help predict and avoid the impacts of Kennedy Space Center's (KSC) frequent thunderstorms which endanger the ground processing, launch, and landing operations of the American Space Program--Space Shuttle, Department of Defense (DOD), and commercial. Special attention has been given to evaluating mesoscale numerical models. The AMU functions under a joint NASA, Air Force (AF), and National Weather Service (NWS) Memorandum of Understanding. AMU tasks during FY 2001 include:

(a) Development and evaluation of statistical forecast tools for winds and ceilings.
(b) Continued evaluation of the Eastern Range Dispersion Assessment System/Regional Atmospheric Modeling System (ERDAS/RAMS).
(c) Development and evaluation of land breeze forecast methodologies.
(d) Development and evaluation of thunderstorm anvil forecast methodologies.
(e) Evaluation and implementation of the Neumann-Pfeffer Thunderstorm Probability Index.
(f) Continued evaluation and implementation of a Local Data Integration System (LDIS) at the NWS office in Melbourne, Florida.
(g) Continued development, evaluation and implementation of tools and techniques for most effective use of the AF WSR-74C radar and its SIGMET processor.
(h) Comparison of Lightning Detection and Ranging (LDAR) antenna systems.



(i) Development, evaluation and implementation of a forecast tool for estimating the time of recovery from violations of the Shuttle Low Temperature Launch Commit Criterion.

(j) Development and implementation of software for operational support to the Airborne Field Mill program (see below).

The KSC Weather Office is improving the weather infrastructure at KSC and conducting research to improve operational processes and facilities. In FY 2001, five suites of visibility and soil moisture sensors were installed to the west of KSC to aid in the forecast of morning fog that could impact Shuttle landings. The Weather Office also conducted a major field research program called "Airborne Field Mill" (ABFM) to collect data necessary to relax the lightning launch constraints while making them even safer. ABFM was cooperatively funded by the Shuttle program, NASA ELVs, and AF. The ABFM team includes more than 50 personnel from eleven organizations including other Governmental agencies, NASA Centers, universities and their contractors. Data analysis should be complete and new launch rules proposed by the end of FY 2002.

The KSC Weather Office, the SMG at JSC, and the AMU continue to work on Range Standardization and Automation (RSA) and the new Spacelift Range Systems Contract (SLRS-C). RSA is a major AF program to modernize the Eastern and Western Range infrastructure. SLRS-C will handle sustaining engineering for what RSA provides. Deliveries of weather sensors, models, and control and display systems began in FY 2000 and will conclude in FY 2003. Transfer of the KSC 50 MHz Doppler Radar Wind Profiler to the Eastern Range and modernization of its electronic components is proposed. There are many issues related to the pending changes to the Eastern and Western Ranges' meteorological infrastructures. The AF and NASA weather communities continue to expend significant resources to solve potential major deficiencies. NASA KSC, JSC and Marshall Spaceflight Center depend heavily on this infrastructure for their weather support.

**SUPPORTING RESEARCH**

The supporting research activities are sponsored by the NASA's Earth Science Enterprise (ESE). The mission of NASA's ESE is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. NASA brings to this endeavor the vantagepoint of space, allowing global views of Earth system change. NASA is a provider of objective scientific information, via observation, research, modeling, and applications demonstration, for use by decision-makers in both the public and private sectors. NASA has been studying the Earth from space from its beginnings as an agency. These efforts have led to our current activity of deploying the first series of Earth Observing System (EOS) satellites that will concurrently observe the major interactions of the land, oceans, atmosphere, ice, and life that comprise the Earth system. In short, the purpose of the Enterprise is to provide scientific answers to the fundamental question:

***How is the Earth changing, and what are the consequences for life on Earth?***

A fundamental discovery made during the 20th century, enabled in large part by NASA's global view from space, is the existence of a multiplicity of linkages between diverse natural phenomena and interactions between the individual components of the Earth system. As a result, NASA has worked with other agencies to develop a new, interdisciplinary field of "Earth system science", with the aim of investigating the complex behavior of the total Earth environment in which the global atmosphere, the oceans, the solid Earth and ice-covered regions of the Earth, and the biosphere all function as a single interactive system. Earth system science is an area of research with immense benefits to the Nation, yielding new knowledge and tools for weather forecasting, agriculture, water resource management, urban and land use planning, and other areas of economic and environmental importance. In concert with other agencies and the global research community, ESE is providing the scientific foundation needed for the complex policy choices that lie ahead on the road to sustainable development.

ESE has established three broad goals through which to carry out its mission:

- Science: Observe, understand, and model the Earth system to learn how it is changing, and the consequences for life on Earth;
- Applications: Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology;
- Technology: Develop and adopt advanced technologies to enable mission success and serve national priorities. These goals are articulated in the ESE Strategic Plan.

NASA and its partners have already made considerable progress in understanding the Earth system. With satellites launched over the past decade, ESE has charted global ocean circulation including the waxing and waning of El Niño, mapped land cover change over the entire globe, illuminated the 3-D structure of hurricanes, and explored the chemistry of the upper atmosphere and the causes of ozone depletion. With deployment of the EOS now underway, ESE is opening a new era in Earth observation from space in which the major interactions of the Earth system are studied simultaneously to provide a global view on climate change. With this knowledge, NASA and its partners will develop prediction capabilities to quantify the effects of natural and human-induced changes on the global environment. Operational agencies such as National Oceanic and Atmospheric Administration (NOAA) and United States Geological Survey (USGS), who are partners in this effort, can use these capabilities to improve weather and climate forecasting, natural resource management, and other services on which the Nation relies.

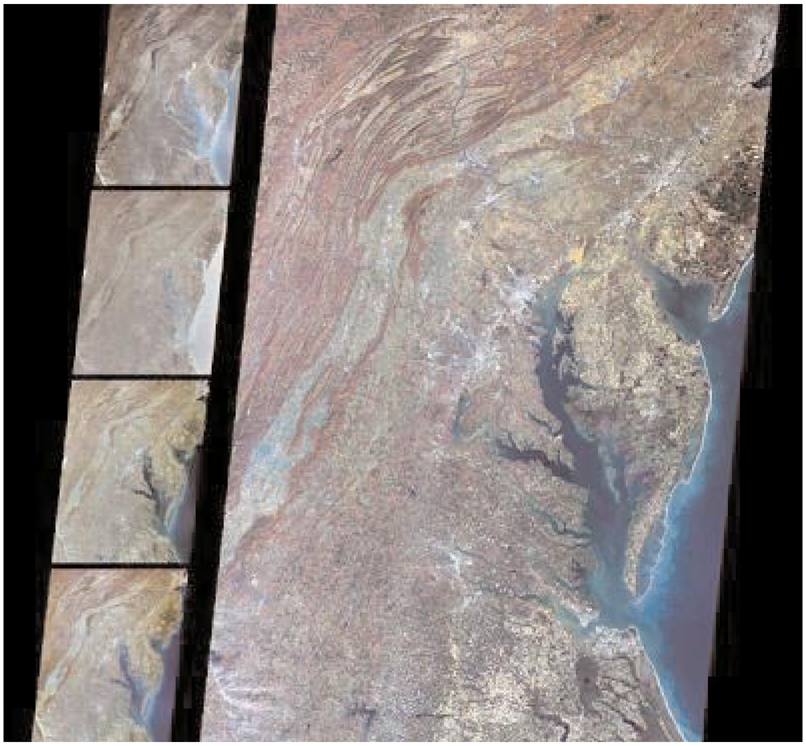


Figure 3-NASA-1. Mid Atlantic states on March 24, 2000 from the Multi-angle Imaging SpectroRadiometer (MISR), on board NASA's Terra satellite. Yellowish smudge at the top of the Chesapeake Bay is likely sediment from the Susquehanna River, flowing into the upper Chesapeake (Source: GSFC web site).

## STRATEGY FOR ACHIEVING GOALS

### Science

We know that natural and human-induced changes are acting on the Earth system. Natural forces include variation in the Sun's energy output and volcanic eruptions which spew dust into the atmosphere and scatter incoming sunlight. Human forces include deforestation, carbon emission from burning of fossil fuels, methane and soil dust production from agriculture, and ozone depletion by various industrial chemicals. Internal climate factors, such as atmospheric water vapor and clouds, also introduce feedbacks that serve to either dampen or enhance the strength of climate forcing. We also know the climate system exhibits considerable variability in time and space, i. e., both short and long term changes and regionally-specific impacts (Figure 3-NASA-1).

NASA has used the concept of Earth System Science in developing its program. Researchers have constructed computer models to simulate the Earth system, and to explore the possible outcomes of potential changes they introduce in the models. This way of looking at the Earth as a system is a powerful means of understanding changes we see around us. That has two implications for Earth Science. First, we need to characterize (that is, identify and measure) the forces acting on the Earth system and its responses. Second, we have to peer inside the system to understand the source of internal variability--the complex interplay among components that comprise the system. By combining observations, research and modeling, we create a capability to predict Earth system change to help our partners produce better forecasts of change.

Earth system changes are global phenomena. Yet the system comprises many micro-scale processes, and the most significant manifestations are regional. Thus, studying such changes requires a global view at regionally discerning resolutions. This is where NASA comes in, bringing the unique capability to study planet Earth from the vantagepoint of space. To characterize the forces acting on the Earth system and its responses, understand the source of internal variability and predict Earth system change, NASA must observe the Earth, conduct research and analysis of the data, model the data and synthesize the information into new knowledge. Where we are on this knowledge "life cycle" determines the strategy for our investment decisions.

The ESE is pursuing a targeted research program, focused on a set of specific science questions that can be addressed effectively with NASA's capabilities. ESE formulates comprehensive research strategies that can lead to definitive scientific answers and potentially to effective applications by other entities.

The key Earth Science research topics sponsored by NASA follow from this view of the Earth as a system. Thus they are grouped into categories of: (a) variability in the Earth System, (b) forces acting on the Earth system, (c) responses of the system to change, (d) consequences of change, and (e) prediction of future changes. Complicating this seemingly linear construct is a set of feedbacks; responses to change often become forces of additional change themselves. This conceptual approach applies in essence to all research areas of NASA's Earth Science program, although it is particularly relevant to the problem of climate change, a major Earth Science-related challenge facing our nation and the rest of the world.

The ESE has articulated an overarching question and a set of strategic science questions reflecting this Earth system approach, which its observational programs, research and analysis, modeling, and advanced technology activities are directed at answering.

- *How is the Earth system changing, and what are the consequences for life on Earth?*
- *How is the global Earth system changing?*
- *What are the primary causes of change in the Earth system?*
- *How does the Earth system respond to natural and human-induced changes?*
- *What are the consequences of changes in the Earth system for human civilization?*
- *How can we predict future changes in the Earth system?*

ESE's Research Strategy for 2000-2010 describes NASA's approach to answering these questions. The intellectual capital behind Earth science missions, and the key to generating new knowledge from them, is vested in an active program of research and analysis. Over 1,500 scientific research tasks from nearly every state within the United States are funded by the Earth science research and analysis program. Scientists from seventeen other nations, funded by their own countries and collaborating with United States researchers, are also part of the Earth science program. These researchers develop Earth system models from Earth science data, conduct laboratory and field experiments, run aircraft campaigns, develop new instruments, and thus expand the frontier of our understanding of our planet. ESE-funded scientists are recognized as world leaders in their fields, as exemplified by the award of the 1995 Nobel Prize in chemistry to two scientists who first recognized that cholorflorocarbons provided a threat to upper atmospheric ozone. The research and analysis program is also the basis for generation of application pilot programs that enable universities, commercial firms, and state and local governments to turn scientific understanding into economically valuable products and services.

<u>Applications</u>

NASA expects that expanded scientific knowledge of Earth processes and the utilization of advanced space-based and airborne observing techniques or facilities developed by NASA will ultimately result in practical applications beneficial to all citizens. Examples of these applications may include: quantitative weather and hydrologic forecasts over an extended range of one to two weeks; prediction of seasonal or longer-range climate variations; the prediction of impacts of environmental changes on fisheries, agriculture, and water resources; global air quality forecasts, and natural hazards risk assessments. NASA ESE has a role in demonstrating the potential applications.

ESE continues to build a viable applications, education and outreach program that bridges our focused Research and Analysis (R&A) and mission science investments towards demonstration of new remote sensing data products for industry and regional and local decision makers. The emphasis is to focus on the dissemination of information to non-traditional Earth science customers, such as states, counties and regional managers and decision-makers. A base program is funded to put the essential tools in place and pilot several key demonstration projects. Eventually we hope that our demonstration of this concept will allow products to reach a much broader user base -practically every state in the Union.

A series of regional workshops have been held around the Nation to enable a wide variety of state and local government users to explain the challenges they face that might be addressed with tools based on satellite remote sensing. One result is the establishment of regular, open, competitively selected opportunities for these organizations to propose partnerships with NASA, academia and industry to demonstrate new applications of Earth science to specific problems. Successful demonstrations are expected to lead to new commercial/state and local government transactions, while ESE moves on to the next new demonstration activity.

<u>Technology</u>

In addition to ensuring a robust science program, this budget contains a vigorous Advanced Technology program that supports development of key technologies to enable our future science missions. In addition to our baseline technology program that includes the New Millennium Program (NMP), Instrument Incubator and High Performance Computing and Communications (HPCC), an Advanced Technology Initiative will identify and invest in critical instrument, spacecraft and information system technologies.

The ESE will lead the way in the development of highly capable, remote and *in situ* instruments and the information system technologies needed to support coupled Earth system models. Together they will enable affordable investigation and broad understanding of the global Earth system. The ESE will emphasize the development of information system architectures to increase the number of users of Enterprise information from hundreds to tens of thousands, with the goal of providing easy access to global information for science, education and applications. Finally, ESE will work in partnership with industry and operational organizations to develop the capabilities and infrastructure to facilitate the transition of sustained measurements and information dissemination to commercial enterprises.

ESE's technology strategy seeks to leverage the entire range of technology development programs offering benefits in cost, performance and timeliness

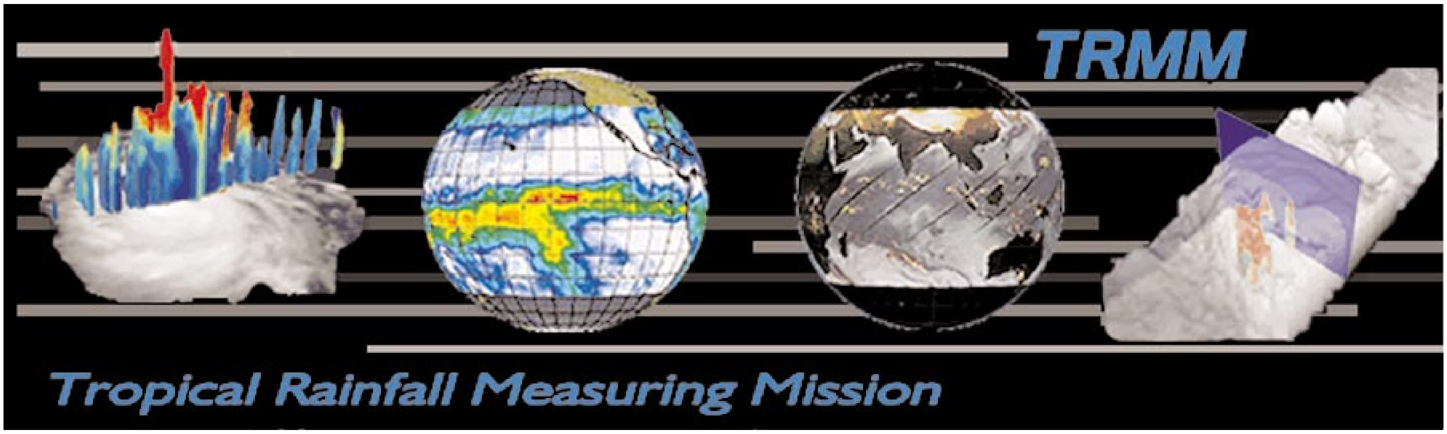



Figure 3-NASA-2. The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan designed to monitor an study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation shaping both weather and climate around the globe (Source: GSFC Web site)

of future Earth science process and monitoring campaigns. ESE's strategy is to establish strong links to other government programs in order to maximize mutual benefit to use open competitions for ESE-sponsored technology programs to attract the best ideas and capabilities from the broad technology community, including industry and academia.

Technology investments will be made in the following areas:

- Advanced instrument and measurement technologies for new and/or lower cost scientific investigations;
- Cutting-edge technologies, processes, techniques and engineering capabilities that reduce development, operations costs, and mission risk and that support rapid implementation of productive, economical, and timely missions;
- Advanced end-to-end mission information system technologies: technologies affecting the data flow from origination at the instrument detector through data archiving, for collecting and disseminating information about the Earth system, and enabling the productive use of Enterprise science and technology in the public and private sectors.

**MISSION IMPLEMENTATION**

The pursuit of Earth system science would be impractical without the continuous, global observations provided by satellite-borne instruments. NASA's Earth science research program comprises an integrated slate of spacecraft and *in situ* measurement capabilities; data and information management systems to acquire, process, archive and distribute global data sets; and research and analysis projects to convert data into new knowledge of the Earth system. Numerous users in academia, industry, federal, state, and local government use this knowledge to produce products and services essential to achieving sustainable development. Enabling us to get at the answers to the science questions, our top priority continues to be our existing near term commitments with the launch of our first series of EOS and selected Earth Explorer missions that are nearing completion. In addition, we are committed to deliver a functioning data and information system to support the processing, archival and distribution of data products for these missions. These satellites will propel the ESE into a new era of data collection, research and analysis for which both the national and international Earth science community has been preparing over the last decade.

Realizing Scientific Return from Past Investments

Preceding the EOS were a number of individual satellite and Shuttle-based missions that are helping to reveal basic processes. The Upper Atmosphere Research Satellite (UARS), launched in 1991, collects data on atmospheric chemistry. The Total Ozone Mapping Spectrometer (TOMS) instruments, launched in 1978, 1991, and 1996, measure ozone distribution and depletion. Two TOMS instruments were launched in 1996, one on the Japanese Advanced Earth Observing System (ADEOS) mission and the other on a dedicated United States Earth Probe. France and the United States collaborated on the Ocean Topography Experiment (TOPEX/ Poseidon), launched in 1992, to study ocean topography and circulation. In 1997, the Tropical Rainfall Measuring Mission (TRMM) was launched to provide the first-ever measurements of tropical precipitation (Figure 3-NASA-2). Also in 1997, ESE began purchasing ocean color data from a commercial vendor based on our joint investment in the Sea-viewing Wide Field Scanner (SeaWiFS) instrument (Figure 3-NASA-3).

Figure 3-NASA-3. High resolution imagery from NASA's Sea-viewing Wide Field Scanner (SeaWiFS) instrument

Opening a New Era in Earth System Science with the Earth Observing System

The EOS, the centerpiece of Earth science, is a program of multiple spacecraft (the Terra, Aqua, Aura, Landsat-7, Jason-1, ICEsat, ACRIMSAT, Seawinds, SORCE, SAGE III, QuikSCAT, and follow-on missions) and interdisciplinary science investigations to provide a data set of key parameters needed to understand global climate change.

Terra was recently launched on December 18, 1999. Terra is providing key measurements that are significantly contributing to our understanding of the total Earth system. The instrument complement is obtaining information about the physical and radiative properties of clouds, air-land and air-sea exchanges of energy, carbon, and water, measurements of trace gases, and volcanology.

Landsat-7 was also launched in 1999. Landsat-7's single instrument, the Enhanced Thematic Mapper Plus (ETM+), is making high spatial resolution measurements of land surface and surrounding coastal regions. This mission is successfully providing data continuity with previous Landsat measurements. Landsat data are used for global change research, regional environmental change studies, and other civil and commercial purposes.

The QuikSCAT spacecraft was launched in June 1999. QuikSCAT, carrying instruments to collect sea surface wind data, is filling the gap in such critical data between ADEOS 1, which failed in June 1997 after seven months on-orbit, and ADEOS II. The availability of components of the Seawinds instrument originally planned for launch on Japan's ADEOS II was accelerated to fly on QuikSCAT. Japan has yet to decide on the timing and form of an ADEOS II mission (or missions), but the ESE still intends to fly a Seawinds instrument in that context as the follow-on instrument to QuikSCAT. It now appears that ADEOS-II will be launched no earlier than 2002 with the delay due to a failure of the Japanese H-IIA launch vehicle.

The Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSat) was launched on December 20, 1999 providing for the continuation of the long-term, quantitative understanding of the solar forcing of Earth's climate.

The Earth Explorers Program contains a series of focused, rapid development missions to study emerging science questions and processes utilizing innovative measurement techniques as a complement to the systematic measurements made through the EOS. The Shuttle Radar Topography Mission (SRTM) flown on STS-99 in February 2000 was a joint NASA and National Imaging and Mapping Agency (NIMA) mission to create a near-global, high-resolution digital elevation topographic map of the world. The data from the SRTM will allow scientists in federal, state and local agencies and academia to study the terrain for basic research in the areas of ecology, geology, geodynamics, hydrology and atmosphere modeling.

Some missions in this category are Earth System Science Pathfinder (ESSP). Four ESSP missions have been selected: (1) Gravity Recovery and Climate Experiment (GRACE) with launch in 2001, (2) Vegetation Canopy Lidar (VCL) with launch TBD (launch date under review), (3) CloudSat with launch in 2003, and (4) the Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations-Climatologie Etendue des Nuages et des Aerosols (PICASSO-CENA) with launch to be determined (launch date is under review). The Earth Explorers Program also encompasses various missions, which are developed in response to requirements that provide or continue highly focused Earth science process measurements. This currently is QuikTOMS (TOMS FM-5) with launch planned for June 2001(Figure 3-NASA-4). Because the launch date for Triana remains uncertain until the Shuttle manifest becomes definitized, Triana will be placed in storage following completion of spacecraft development. In addition, the University Earth System Science (UnESS) program is being cancelled to fund immediate priorities in the Earth Science budget. A small amount of funding will be retained for these activities to complete contractual obligations associated with proposal evaluations.

EOS and related missions in development and preparation for launch through 2003 are:

- QuikTOMS (2001) - Atmospheric ozone and aerosols
- SAGE III (2001) - Stratospheric aerosols and gases experiment
- Jason (2001) - ocean topography; successor to TOPEX/ Poseidon
- Aqua (2001) - atmospheric temperature and humidity, clouds, sea surface temperature, biosphere
- GRACE (2001) - time variations of Earth's gravity field
- ICEsat (2001/ 02) - ice sheet topography
- SORCE (2002) - solar irradiance
- SeaWinds (2002) - on Japan's ADEOS II satellite; ocean winds successor to QuikSCAT
- Vegetation Canopy Lidar (TBD) - Forest canopy height
- Aura (2003) - Upper and lower atmospheric chemistry
- Cloudsat (2003) - 3-D cloud profiles
- PICASSO-CENA (TBD) - 3-D aerosol profiles

The EOS Data and Information System (EOSDIS) is operating the EOS satellites now in orbit, and retrieving flight data and converting it into useful scientific information. EOSDIS is nearly complete; remaining segments are timed for release to support the upcoming launches of EOS missions through Aura in 2003. Following the recommendation of the National Research Council, NASA is exploring the creation of a federation of Earth science information partners in academia, industry and government to broaden the participation in the creation and distribution of EOSDIS information products. As a federation pilot project, 24 organizations were competitively selected in December 1997 to become Earth Science Information Partners (ESIPs) to develop innovative science and applications products. This is part of a broader analysis of how ESE's approach to data

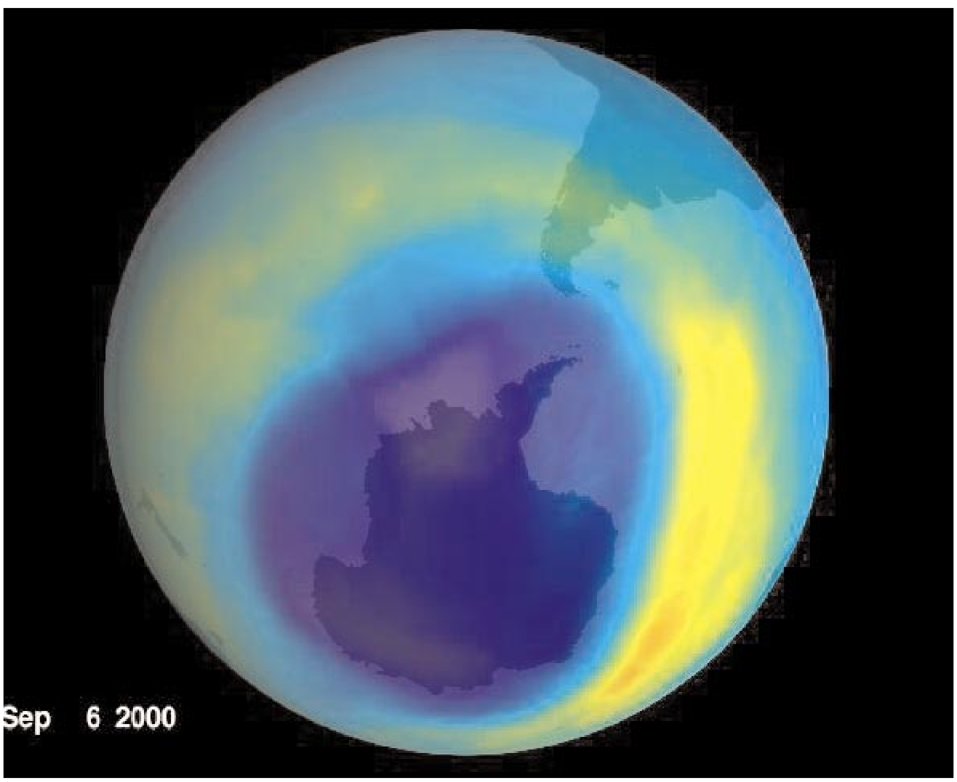



Figure 3-NASA-4. Largest-ever Ozone hole, roughly three times the size of the United States, was detected on September 6, 2000 by NASA's Total Ozone Mapping Spectrometer (TOMS) (Source: GSFC website)

and information systems services should evolve in the future. In addition to the EOSDIS that will produce data products for a wide range of users, NASA is engaging in a variety of activities to extend the utility of Earth Science data to a broader range of users such as regional Earth science applications centers, Earth science information partners, and efforts are under way to fuse science data, socio-economic data and other data sets that can be "geo-referenced" in readily understandable data visualizations.

The measurements to be made by these and other future Earth science missions as well as current on-orbit missions provide data products that are used extensively in the Earth science program. These activities are providing an ever increasing scientific understanding of global environment and the effects of natural and human sources of change.

Preparing for the Next Decade of Scientific Discovery

In parallel with deploying EOS, NASA ESE is looking ahead to determine what will be the important Earth science questions in the next decade, and which require NASA's leadership to be answered. Drawing on existing reports of the National Academy of Sciences and the state of progress in current scientific endeavors, ESE has developed a Research Strategy for 2000-2010 that articulates a hierarchy of one overarching question, five broad subordinate questions, and twenty-three detailed questions that can and should be tackled over this decade. For each, the Research Strategy defines the observational requirements, which in turn provide the basis for definition of candidate missions to be pursued. An early, high priority in this timeframe is the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Program (NPP), which will serve to provide continuity with the Terra and Aqua missions as well as a demonstration of instruments for the converged weather satellite program. NASA and the Integrated Program Office (IPO) jointly fund the NPP mission. The IPO consists of representative from the three agencies participating in NPOESS-NASA, NOAA, and the AF. Another priority is the Landsat Data Continuity Mission to succeed Landsat-7. As with Landsat-7, this mission is being planned in partnership with the USGS. NASA and USGS are also working with industry to explore the potential for a commercial purchase of Landsat-type data to meet this data continuity requirement.

In NASA's FY 2001 appropriation, Congress included funds for concept definition work for potential missions to observe global precipitation, global earthquakes, and global tropospheric winds. Studies are underway, with further definition work anticipated to proceed in FY 2002. Also in FY 2002, ESE plans to begin similar definition activities for observation of global ocean topography and ocean surface winds to succeed Jason and SeaWinds on ADEOS II, respectively. Beginning in FY 2001, NASA is soliciting its third round of ESSP missions, with selection(s) anticipated in FY 2002.

In developing its measurement/mission strategy, the ESE desires to reduce the risk to overall program objectives from any single mission failure by developing smaller, less expensive missions and implementing shorter development cycles from mission definition to launch. Shorter development times will allow more flexible responses to current and evolving scientific priorities and more effective uses of the latest technologies. In accordance with this philosophy, the implementation of each successive future mission in the ESE flight program will be based on specific solicitation alternatives (e.g. Announcement of Opportunity, Request for Proposal, etc.) and competitive selection of instrument payloads and implementation options. In each solicitation, we will ask commercial industry to come forward and offer science-quality data that meet NASA requirements for NASA to purchase. It is important, under this new approach, that instrument technology developments be conducted largely before the relevant mission payload selection. A science and applications-based space-based measurement concept set is indispensable to guide these pre-mission technology developments, particularly the Enterprise's Instrument Incubator Program. Our goal is to reach a mission development cycle of 2-3 years from the time of selection.

Finally, along with space-based observations, ESE will pursue a guided evolution of data and information system services to support missions and research in the next decade. NASA's FY 2001 appropriation also included funds to develop the "NewDISS" concept for this evolution. Studies in this arena are underway as well.

**PARTNERSHIPS ARE ESSENTIAL TO SUCCESS IN EARTH SCIENCE**

The challenges of Earth System Science, sustainable development, and mitigation of risks to people, property and the environment from natural disasters, require collaborative efforts among a broad range of national and international partners. NASA's Earth science research program constitutes its contribution to the United States Global Change Research Program (USGCRP), an interagency effort to understand the processes and patterns of global change. The USGCRP coordinates research among ten United States government agencies. NASA is by far the largest partner in the USGCRP, providing the bulk of USGCRP's space-based observational needs.

NASA has extensive collaboration with the NOAA on climate-related issues. The ESE is the responsible managing agent in NASA for the development of NOAA's operational environmental satellites. NOAA, NASA, and DOD jointly work to achieve the convergence of civilian and military weather satellite systems. NASA collaborates with the USGS on a range of land surface, solid Earth and hydrology research projects. NASA and USGS collaborate in the Landsat-7 program, and NASA, DOD and USGS are working together on a third flight of the Shuttle Radar Laboratory modified to yield a digital terrain map of most of the Earth's surface. NASA participates in the World Climate Research Program, the International Geosphere/Biosphere Program, and the ozone assessments of the World Meteorological Organization.

International cooperation is an essential element in the Earth science program. Earth science addresses global issues and requires international involvement in its implementation and application. Acquiring and analyzing the information necessary to address the science questions is a bigger task than a single nation can undertake. Furthermore, the acceptance and use of the scientific knowledge in policy and resource management decisions around the world require the engagement of the international scientific community. Global data and global participation are needed to devise a global response to environmental change. In addition, integrating our complementary science programs can result in fiscal benefits to the NASA program. For this reason, NASA has sought and nurtured international partnerships spanning science, data and information systems, and flight missions. Most of Earth science's satellite missions have international participation, ranging from simple data sharing agreements to joint missions involving provision of instruments, spacecraft, and launch services. In the past three years over 60 international agreements have been concluded and more than 40 more are pending. In some capacity, Earth science programs involve international partners from over 35 nations, including Argentina, Armenia, Australia, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, India, Israel, Italy, Japan, Mongolia, Russia, South Africa, Ukraine and others.

**SPACE WEATHER** The Living With A Star (LWS) Program (Figure 3-NASA-5) addresses the linkage between three fundamental questions of the NASA solar-terrestrial physics program's the Sun Earth Connection (SEC) program:

- How and why does the sun vary?
- How does the Earth respond to solar variations?
- How does solar variability affect life and society?

The SEC Program strives to understand the physical processes and connections that control the dynamics of the Sun-Earth connected system. The system dynamics are driven by violent solar bursts, long term solar variability, and instabilities of the magnetized Earth-space, geospace. LWS is grounded in service to humanity and it's technological systems. It is based on solving the specific problem of being able to predict solar variations and the effects of those variations on humanity and human systems. LWS will integrate results from existing and future space missions as they contribute to the SEC system level goals. The program is based on providing the understanding necessary to predict what will happen where and when to the heliosphere, geospace, and Earth's

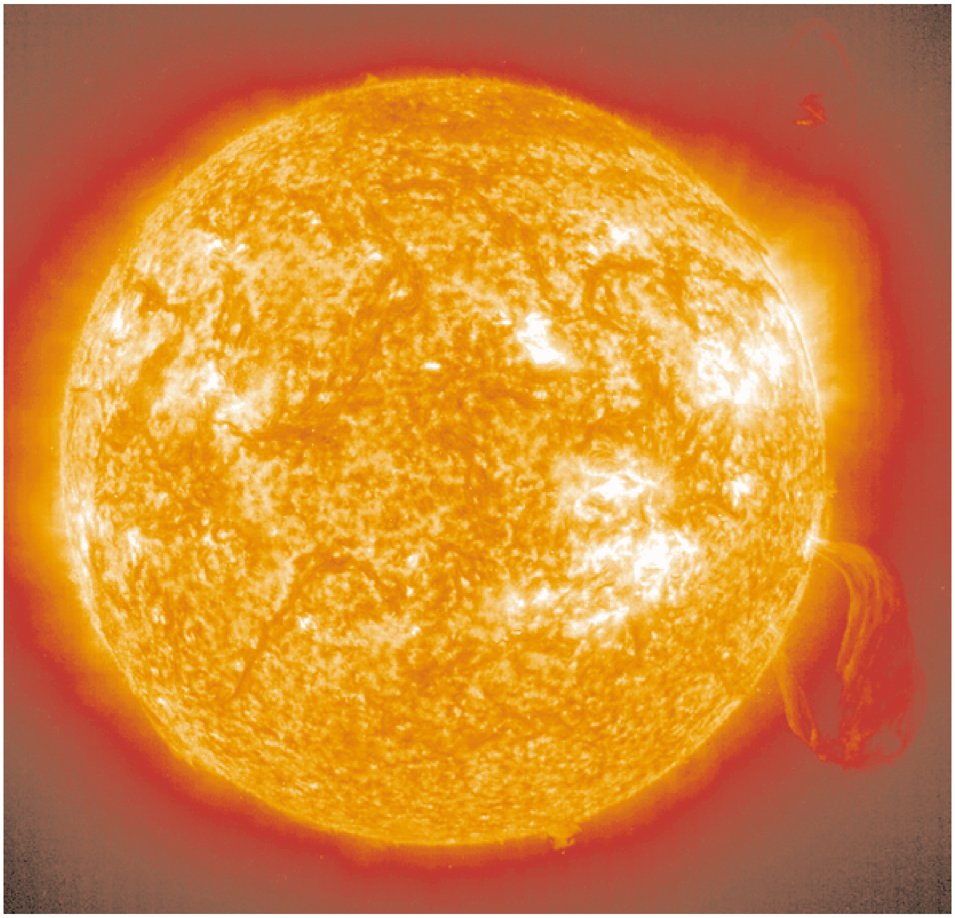


Figure 3-NASA-5. Bulbous prominence -- A large, twirling prominence taken on February 12, 2001. Prominences are huge clouds of relatively cool dense plasma suspended in the Sun's hot, thin corona. At times, they can extend outward and break away from the Sun's atmosphere. This image shows ions of helium heated at 60,000 degrees C.

climate given observations of conditions on the Sun.

While both existing SEC programs and LWS are basic research, there are some significant differences in concept and approach. The primary difference is that in addition to the traditional input from the space science community, LWS derives requirements from Earth science, human spaceflight, industry and other federal agencies (National Space Weather Program, Office of the Secretary of Defense Space Weather Architecture, DOD, NOAA, FAA). The LWS Program has characteristic features: there is a significant component that deals with specification models; what is the environment as a function of space and time. This is an important need for industry that must build spacecraft that survive, and to provide anomaly resolution. There is a need for human spaceflight radiation protection. Finally, there is the issue of prediction, which is the more traditional science.

The program priorities are (numbers indicate priority rank):

(1) Solar influences on Global Change: Global change is the single most important environmental problem facing humanity. This issue involves major national and international policies because of the potential economic impacts of global change and/or mitigation actions. Objectives:

- Determine how and why the Sun varies (for assessment of past and future role in global climate change).
- Identify and understand mechanisms by which solar variability affects terrestrial climate (and possibly weather).

(2) Space environmental "climate" data (e.g., specification models):

- Needed for design of cost-effective systems with minimal or no sensitivity to space weather.
- The goal is to have economical "all weather" systems; not to be dependent on predictions.

(3) Nowcasting space environment:

- For rapid anomaly resolution for space and communication/navigation systems--if an anomaly is due to a known space environmental effect, it is often possible to get back into operation rapidly. If it is due to an unknown cause, it may be necessary to do detailed failure analysis--requiring extended downtime of the affected system.
- Astronauts safety--in the event of significant radiation, astronauts can move to shielded areas.

(4) Prediction of:

- Solar Proton Events (astronaut/airline flight safety). Goals: (a) reliable warnings (minimize false alarm rate) and (b) reliable forecast of "all clear" periods for EVA's.
- Prediction of geomagnetic storms for applications where effective mitigation is possible (e.g. electric power grid). Goals--reliable forecasts (storm is coming) and very reliable shorter term (~hour) warnings to minimize unnecessary mitigation by reducing capacity, etc. which can reduce system efficiency.
- Predictions of space environment for operation and utilization of space systems. Goals: (a) reliably forecast availability/accuracy/sensitivity of communication and navigation systems susceptible to space weather (e.g. ionospheric scintillations) and (b) enable optimization of systems and the allocation of resources during times of extreme space weather conditions.

In summary, LWS will characterize the space environment with the aim being to help spacecraft designers and operators, and address astronaut health and safety. LWS will produce the system knowledge to predict solar effects on climate, and solar/geospace effects on human systems in space and on the ground.

The approach to achieving our goals is to treat the Sun, heliosphere, and geospace as a system. The key to dealing with the problem as a system is to understand that physics-based models will be the "glue" that holds the system together. It is assumed that ultimately reliable and serviceable models combined with key observations of the SEC system will allow the prediction of what will happen--where and when. Model requirements will drive what observations are needed for boundary conditions and "truth" tests of the models.

The present approach to implementing a systems-based program is to define the management structure along scientific problem lines. The space environment research area includes the effects of solar variability on climate and global change as well as specification of radiation and density models. The space storms area includes the specification of the environment on a more real-time or nowcasting and event basis. Included as well is the ultimate goal of the LWS, the physical understanding of the end-to-end Sun-Earth system, enabling reliable predictive capability of storm effects. The program has the following elements: (1) a Space Weather Research Network of solar-terrestrial spacecraft; (2) a theory, modeling, and data analysis program; and (3) Space Environment Testbeds (SET) for flight testing radiation-hardened and radiation-tolerant systems in the Earth's space environment. Vital to the success of LWS and critical to the satisfaction of national needs is the development of partnerships with national and international agencies and industry.

Implementation of LWS will proceed in two phases. The first phase will include: (1) a geosynchronous spacecraft that will observe the Sun from its interior (via helioseismology techniques) to the outermost extensions of its atmosphere where solar activity produces the variable solar output of electromagnetic radiation, solar wind, and energetic particles, and (2) the Geospace Mission, a set of spacecraft to understand geospace as a function of time and the effects of solar events and local instabilities on its evolution. The second phase will add a set of heliospheric spacecraft to determine the state of the solar wind and the propagation of events.

**AVIATION SAFETY PROGRAM**

NASA's Aviation Safety Program is aggressively pursuing three primary areas:

- Aviation Weather Information Distribution and Presentation: This effort includes combining the inputs from a variety of sources of weather data into a convenient, cockpit display that is simple and easy for the pilot to comprehend. It will likely be a multi-function flat panel display that will display all forms of weather, terrain and traffic hazards (Figure 3-NASA-6 and Figure 3-NASA-7).
- Synthetic Vision in the Cockpit: Synthetic Vision is electronically enhanced vision for the pilot. It combines a very detailed world wide terrain map (obtained from a recent Space Shuttle mapping mission), precise GPS navigation data, and integrity-monitoring sensors to provide a realistic view of the world through a cockpit head-up-display (HUD) or panel mounted display. The pilot will look through the HUD as he or she looks out the window. This see-through HUD will make the world look like a bright sunny day even when the airplane is approaching a fogged-in airport at midnight--one that would be shut down under today's operating rules.
- Turbulence Detection: This project is the development of aircraft-mounted, forward looking turbulence detectors that look several kilometers ahead of the aircraft using Lidar and radar sensors. A suitable cockpit warning device would alert pilots of impending encounters. There is also work in ground based detection (Figure 3-NASA-8).

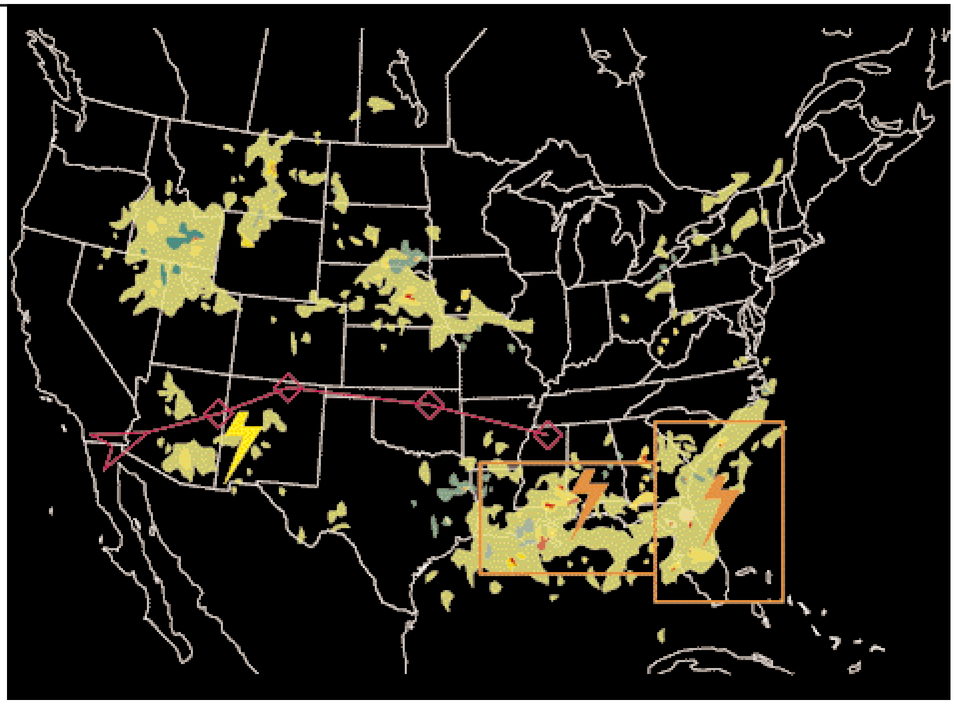


Figure 3-NASA-6. Cockpit display of national weather radar mosaic.

NASA's Icing Research is pursuing a large number of areas that affect aircraft in flight. Primary examples of this effort are:

- The development of icing training videos and other materials will help educate pilots on all aspects of aviation icing.
- The development of improved wind tunnel and analytical techniques to predict icing accumulation patterns on wings, tails, and inlets will help designers improve future aircraft and engines.
- Forward looking, aircraft mounted detectors will detect moisture laden clouds miles ahead of the aircraft. Adding air temperature, pressure, and humidity to the data received from the sensors, computers will compute the icing potential of the approaching cloud and will display "high risk areas" to the pilot in an easily read, color cockpit display.
- Sensors that measure the accumulated ice on aircraft in-flight will automatically activate, new, low cost de-icing devices that will shed the ice before the aircraft gets in danger.
- The potential for satellite detection of icing conditions is being investigated.

<u>General Aviation</u>

NASA's General Aviation element is actively researching new, low power, and low cost pneumatic and electrical ice removal technology. Also in development are low cost displays that graphically show icing weather information so icing conditions can be avoided during flight planning.

<u>Terminal Area Productivity</u>

NASA's Terminal Area Productivity element is contributing via these areas:

- Wake vortex detection/prediction to improve the efficiency of aircraft spacing.
- A heads up display that electronically displays the edges of taxiways and runways, shows ground traffic and marks clearance routes to gates and/or runways. All this is overlaid on the pilot's "real world" view out the window while stereo headphones allow the pilot to hear ground traffic from the direction the other aircraft really are. This technology will be a great aid to vision in poor visibility--especially at unfamiliar airports.

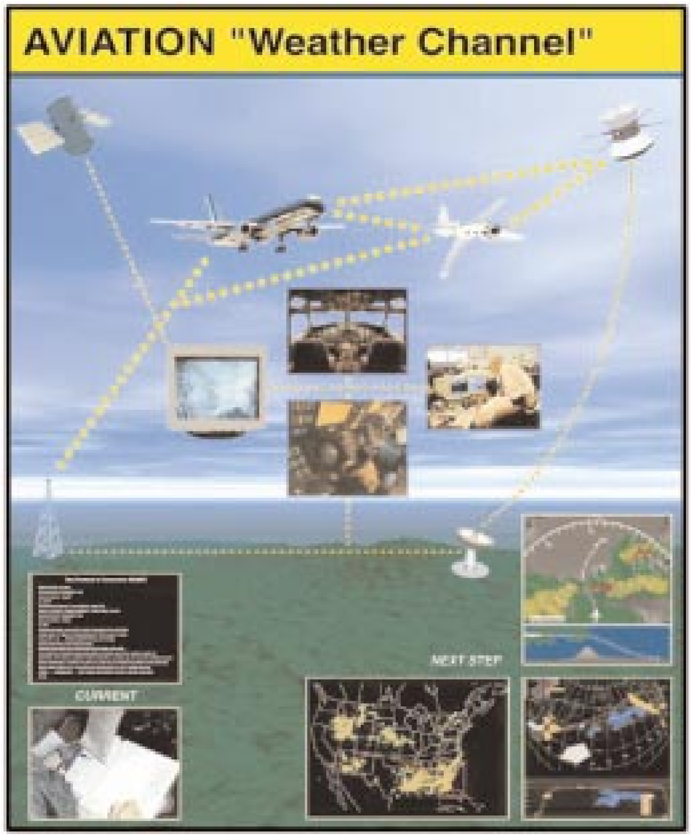


Figure 3-NASA-7. Communication and distribution channels for Aviation weather information.

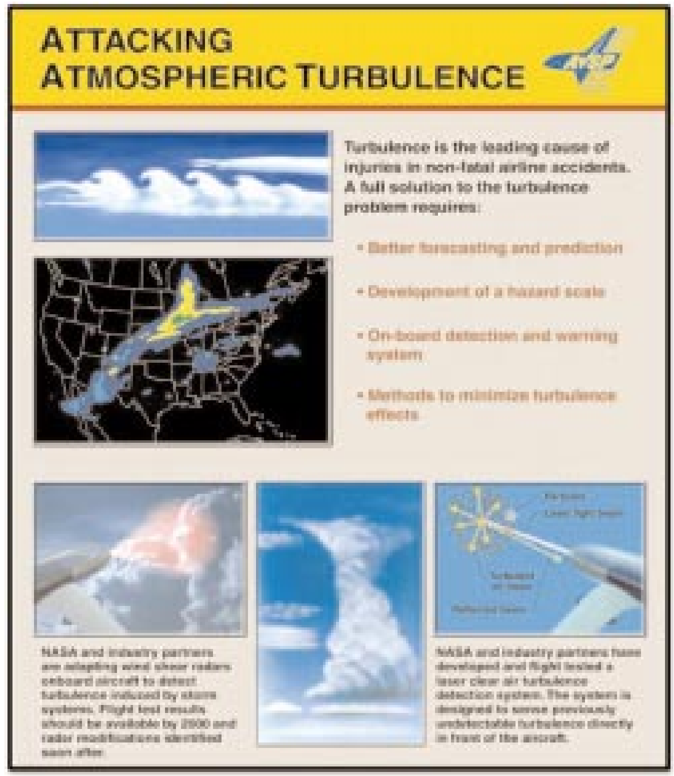


Figure 3-NASA-8. NASA's Aviation Safety Program plans to detect atmospheric turbulence through the use of advanced technologies.

- A look down electronic display shows a bird's eye view of the airport as if the pilot were looking at the airport on a bright sunny day from about 1,000 feet above the airport. The position of all runways, taxiways, buildings, and ground traffic is clearly displayed--as is the exact route the pilot is cleared to take to get to the gate or the runway. Another huge aid to vision in bad weather.

As with virtually all of NASA's aviation research, most of the research mentioned above also helps pilots in good weather too.